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Report Title:	Review of Surface Hydrology in the Orange River Catchment
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1 INTRODUCTION

1.1 General

The Orange River originates in the Lesotho Highlands and flows in a westerly direction 2 200 km to the west coast where the river discharges into the Atlantic Ocean (see **Figure 1-1**). The Orange River basin is one of the largest river basins south of the Zambezi with a catchment area of approximately 0.9 million km^2.

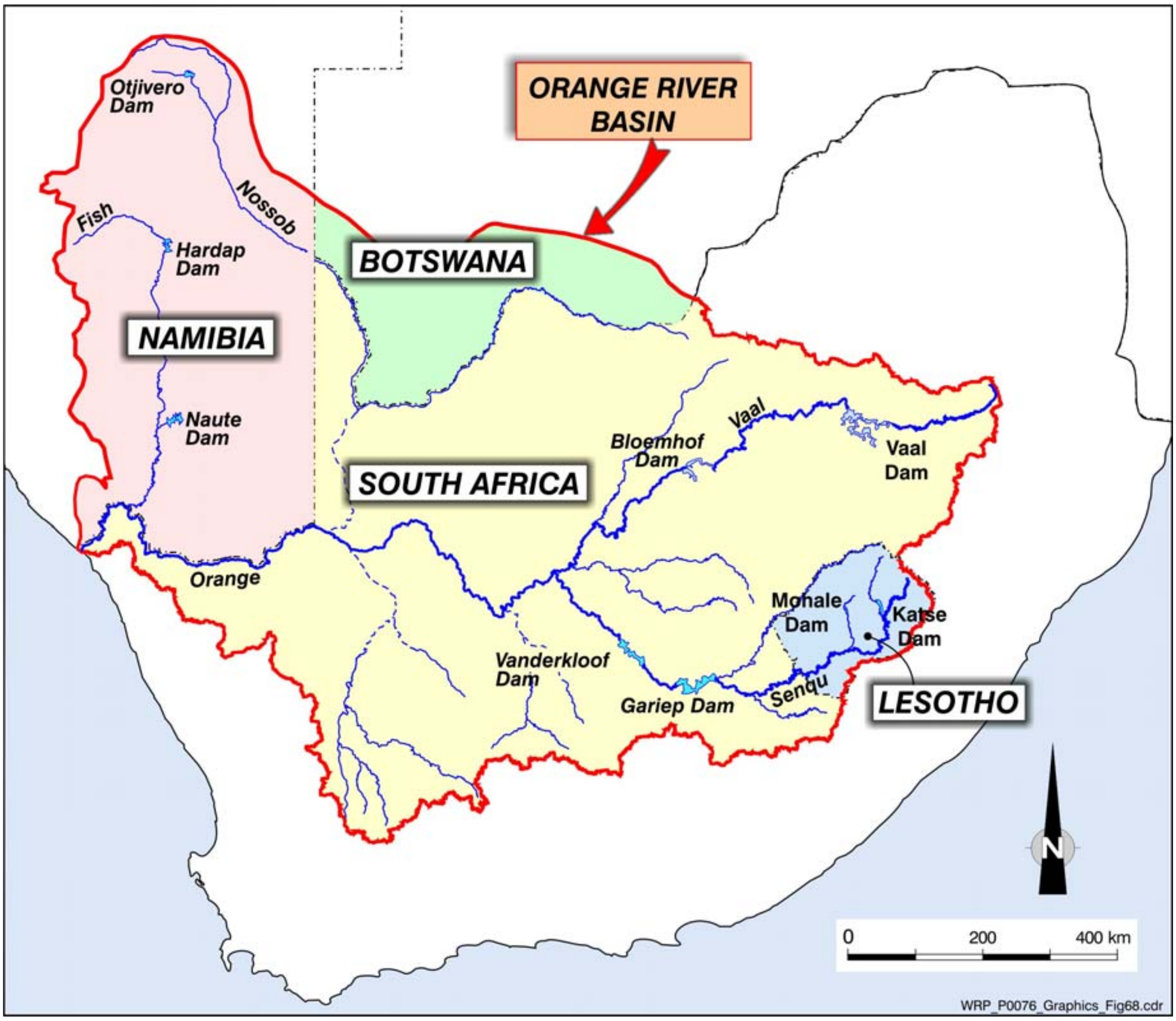

Figure 1-1: Orange River

It has been estimated that the natural runoff of the Orange River basin is in the order of 11 600 million m^3/a of which approximately 4 000 million m^3/a originates in the Lesotho

Highlands and approximately 900 million m^3/a from the contributing catchment downstream of the Orange/Vaal confluence which includes part of Namibia and a small portion in Botswana feeding the Nossob and Molopo rivers. Whether or not these two rivers directly contribute to the Orange River is an outstanding issue which will be addressed during the study. The remaining 6 700 million m^3/a originates from the areas contributing to the Vaal, Caledon, Kraai and Middle Orange rivers. (see **Figure 1-2**).

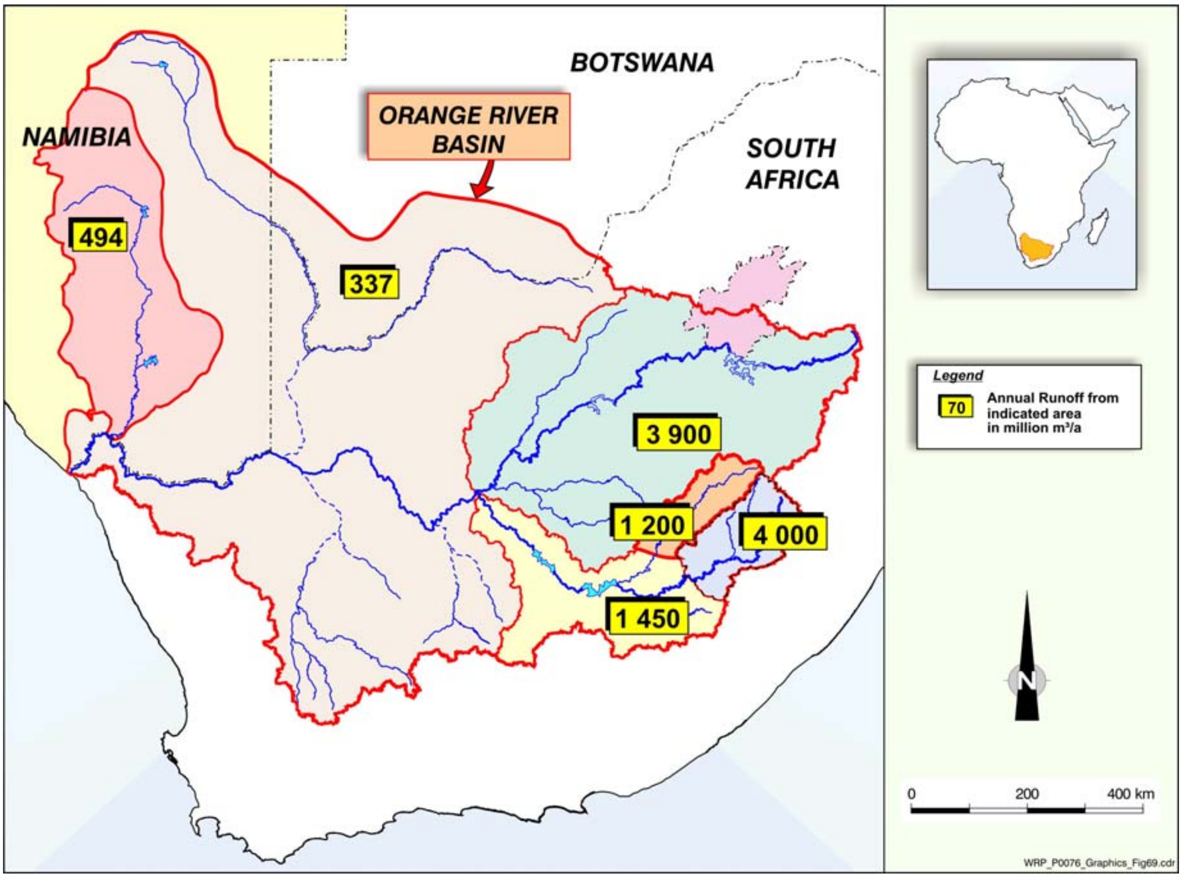

Figure 1-2: Approximate Water Balance for Natural Runoff in the Orange River Basin

Error! Reference source not found.It should be noted that much of the runoff originating from the Orange River downstream of the Orange Vaal confluence is highly erratic (coefficient of variability greater than 2) and cannot be relied upon to support the various downstream demands unless further storage is provided.

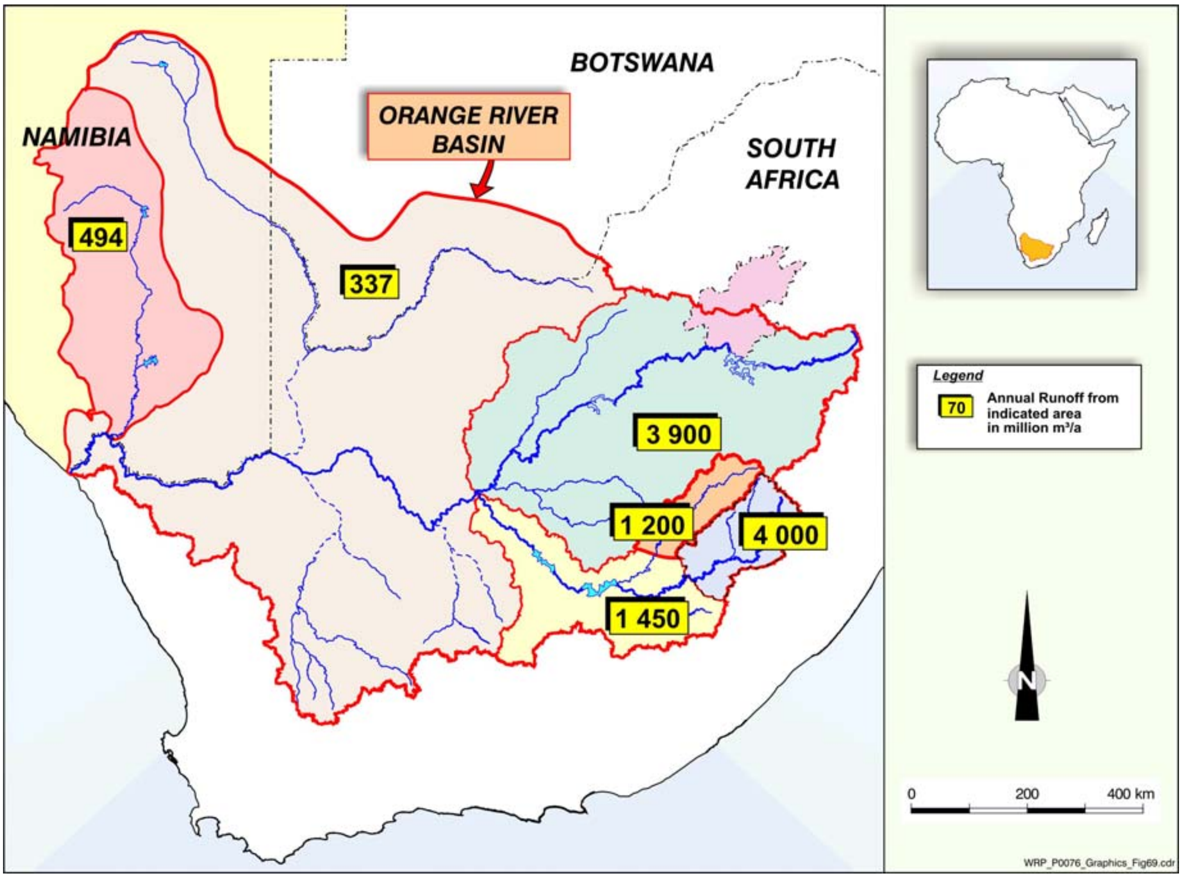

Figure 1-2: Approximate Water Balance for Natural Runoff in the Orange River Basin

The water flowing into the Orange River from the Fish River in Namibia (near the river mouth) could theoretically be used to support some of the downstream demands, particularly the environmental demands at the river mouth. To date, however, the contributions from the Fish River (in Namibia) cannot be utilised to support any downstream demands since these demands are currently supplied with water from Vanderkloof Dam which must be released well in advance since the water takes 2 to 6 weeks to reach the mouth (some 1 400 km away). Any water flowing into the Orange River from the Namibian Fish River will therefore add to the water already released from Vanderkloof Dam since it is currently not possible to stop or store the additional water once it has been released.

The figures indicated in **Figure 1-2** refer to the natural runoff which would have occurred had there been no developments in the catchment. The actual runoff reaching the river mouth (estimated to be in the order of 5 500 million m^3/annum) is considerably less than the natural value (over 11 000 million m^3/annum). The difference is due mainly to the extensive water utilisation in the Vaal River basin, most of which is for domestic and industrial purposes. Large volumes of water are also used to support the extensive irrigation (estimated to be in the order of 1 800 million m^3/annum) and some mining demands (approximately 40 million m^3/annum) occurring along the Orange River downstream of the Orange/Vaal confluence (see **Figure 1-3**) as well as some irrigation in the Lower Vaal catchment and Eastern Cape area supplied through the Orange/Fish Canal (see **Figure 1-4**Error! Reference source not found.) (Eastern Cape Fish River). In addition to the water demands mentioned above, evaporation losses from the Orange River and the associated riparian vegetation account for between 500 million m^3/a and 1 000 million m^3/a depending upon the flow of water (and consequently the surface area) in the river (Mckenzie et al, 1993, 1994 and 1995). An approximate water balance for the Orange River is provided in **Table 1-1** to provide perspective on the various demands supported from the river.

Several new developments have already been commissioned or have been identified as possible future demand centres for water along the Lower Orange River. In Namibia such developments include the Haib copper mine, Skorpion lead and zinc mine (already developed), the Kudu gas fired power station at Oranjemund and several irrigation projects for communal and commercial irrigation along the northern riverbank. Similar potential also exists on the South African side of the river with particular need to develop irrigation for previously disadvantaged farmers. In Lesotho there is considerable development planned for the Lesotho Lowlands area and also the potential for further transfers from the Lesotho Highlands Water Project. In Botswana, the developments that may influence the Orange River are restricted mainly to groundwater abstraction.

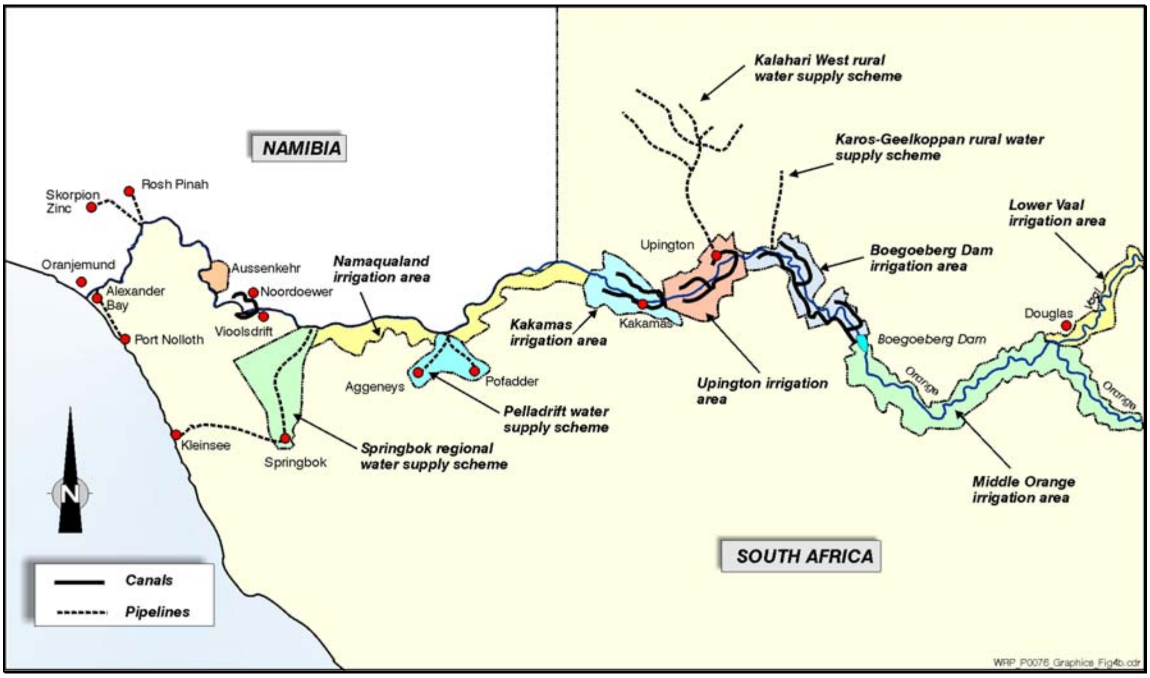

Figure 1-3: Major Water Demands along the Lower Orange River.

Table 1-1: Orange River Water Balance at 2005 Development Level

Water Balance Component	Volume (million m³/a)
Environmental Requirement	900 (1)
Namibia	120 (2)
Lesotho & Transfers to RSA	820 (3)
RSA Orange River Demand	2 560 (4)
RSA Vaal River Demand	1 560 (5)
Evaporation & losses	1 750 (6)
Spillage	3 780 (7)
Total	**11 490**
Spillage under natural conditions	10 900

Notes (1) - Includes natural evaporation losses from Orange River.

(2) - Includes water use from Orange & Fish rivers.

(3) – With Full Phase 1 of LHWP active.

(4) – Includes transfers to the Eastern Cape.

(5) – Vaal Demand supplied from locally generated runoff.

(6) – Excludes evaporation losses from the as it is already included in component 1.

(7) – Average spillage at 2005 development level

In Lesotho, the first phase of the Lesotho Highlands Water Project was recently completed and represents one of the largest water transfer schemes in the world. Some details of the scheme are shown in **Figure 1-5**. It should be noted that the water transfers shown in the figure are approximate values only and are likely to change due to revision of environmental requirements etc.

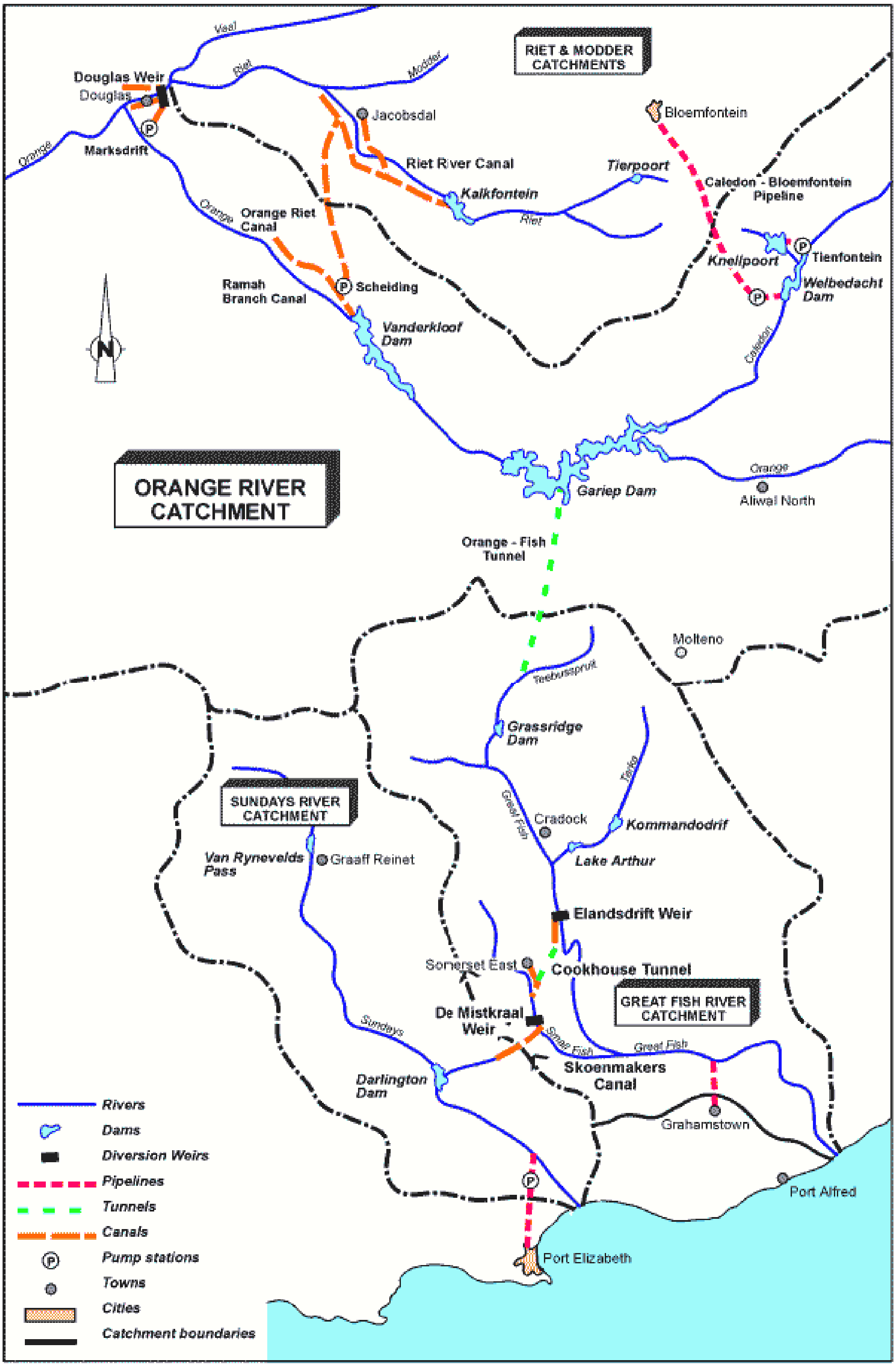

Figure 1-4: Major Water Transfer Schemes from Gariep and Vanderkloof dams.

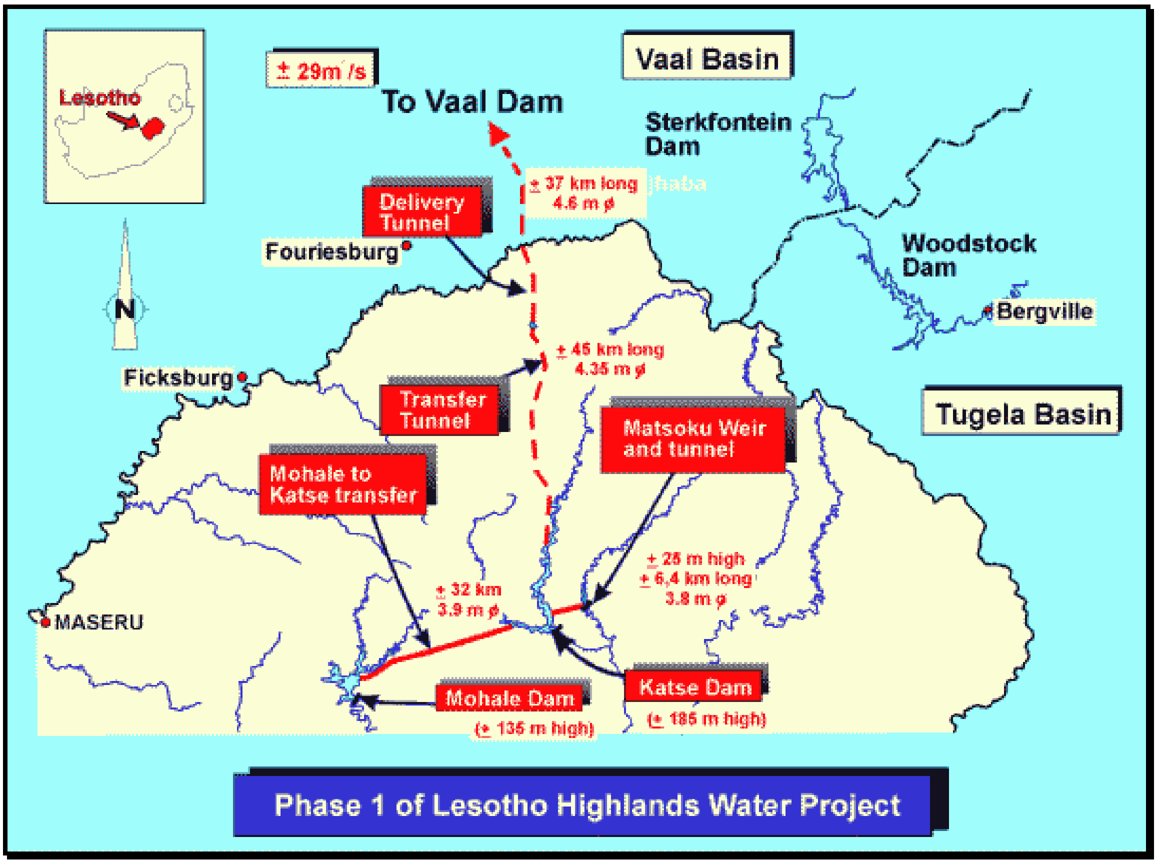

Figure 1-5: Phase 1 of the Lesotho Highlands Water Project.

1.2 Objective of the study

In view of the existing and possible future developments which will influence the availability of water in the Orange River, a project has been initiated by ORASECOM and commissioned and funded by GTZ involving all four basin states (Botswana, Lesotho, Namibia and South Africa. The main objective of the project is to facilitate the development of an Integrated Water Resources Management Plan for the Orange River Basin. The plan will in turn facilitate the following specific objectives:

- Maximise benefits to be gained from Orange River water;
- Harmonise developments and operating rules;
- Foster peace in the region and prevention of conflict;
- Encourage proper and effective disaster management;

- Ensure that developments are sustainable and encourage the maintenance of bio-diversity in the basin, and
- Management of potential negative impacts of current and possible future developments.

In order to achieve the above objective it is envisaged that the resulting Water Resources Development Plan will be founded on the following four basic principles:

- Reasonable utilisation of available water resources;
- Equitable accrual of benefits to basin states;
- Sustainable utilisation of water resources, and
- Minimisation of harm to the environment.

The strategy to be adopted by the project team to meet the objectives should involve the following:

- Sharing of information on existing and proposed future developments;
- Facilitation of a common understanding of key issues based on comparable technical and institutional capacity;
- Development of comparable legislation and institutional structures;
- Adoption of comparable standards and management approaches;
- The development of a Water Resource Management Plan for the future development and management of the water resources of the Orange River.

It is anticipated that the development of the Water Resource Management Plan will be undertaken in phases and the remainder of this document refers to the work involved with Phase 1 of the project. Phase 1 will involve the following:

- A desktop study to establish the status quo within the basin and to create an agreed base from which the subsequent phases of the project can be developed;
- To facilitate capacity building where possible in order to strengthen expertise throughout the four basin states;
- To identify and highlight deficiencies in the knowledge base which must be addressed before the Water Resource Management Plan can be finalised. Some fieldwork may be required in subsequent phases of the project;
- To develop a preliminary Water Resource Management Plan which can be used as the basis from which the final plan can ultimately be developed;

- To develop a draft scope of work for subsequent phases of the project from which a Terms of Reference can be developed by the Client.

An inaugural meeting to discuss the project and in particular the expected content for the Inception Report was held in Botswana on 8 February 2004.

1.3 Purpose and Structure of this Report

This report will be used to summarise the findings from the two main components of the hydrology review task. The first component is the data base inventory. A description of the data base inventory along with summaries on pertinent data and data gaps are given in **Section 2** of the report. The second component includes a description of the situation assessment of the prevailing hydro-meteorological conditions, in the Orange River Basin, given in **Section 3**. Conclusions and recommendations are given in **Section 4**.

2 DATA BASE INVENTORY

2.1 General

This component of the hydrology review task involved the compiling of the latest available hydrological and related data from reports of relevant studies. As part of this component an importance index and data confidence ranking system was developed to be able to classify the available hydrological information. Gaps in the hydrological information were identified in the process and indicated on a geographical coverage. An initial database was developed in Excel which will later in the study be incorporated in the Access database which is developed as part of Task 2 of this study. The preliminary Excel data base was populated with metadata such as MAR, MAP, record periods, data importance and data confidence, evaporation etc. as obtained from existing reports. Details of the importance index and data confidence ranking system as well as for the database inventory will be given in the sections to follow.

2.2 Importance Index and data confidence ranking system

The data importance index was developed and used to provide an indication of the importance of a specific hydrological related data element. The data importance index that was developed for this purpose and also used in the population of the data inventory is given in **Table 2-1**.

Table 2-1: Data importance index

Rating (0 to 5)	Description
0	Not required
1	Useful background information
2	Nice to have – will add very little value to the hydrology but will assist in the broader understanding of the hydrology
3	Valuable – will add substantial value to the hydrology
4	Important – required to obtain reliable hydrology
5	Essential – Cannot do without

The data confidence ranking system in turn was developed to provide and indication of the confidence one has in the available hydrological data as given in the latest study reports. Separate data confidence ranking systems were developed for different types of data as the characteristics of the different data types required this. The rating system for the observed flow data includes two parameters. The first parameter on a scale A to D gives an indication of the quality of the observed flow and relates to the effort made to check, verify and patch the observed record. The second parameter gives an indication of the accuracy of the data on a scale 0 to 5 where 5 is excellent and 0 so poor that it is not recommended for use in hydrological analyses. This means that one can have a record of high quality (A) which means that this observed record was properly checked, verified and patched but the accuracy is only reasonable. The rating for this record will then be given as an A3 (see **Table 2-2** for more detail). The rating systems for the other data types are relatively simple and are indicated by a single parameter as shown in **Table 2-2**.

Table 2-2: Data confidence ranking system

Data and rating description	Rating	Additional rating description and notes	
Observed flow data		Accuracy Rating 0 - 5	Typical conditions / descriptions
Observed checked & verified & patched	A	0 – not to be used	Accuracy poor – weekly recording – short record length - > 20% gaps unreliable months
Observed checked and verified	B	1 – poor	Accuracy suspect – daily recording – short record length - > 15% gaps unreliable months
Observed no checking/verification	C	2 – use with caution	Accuracy reasonable - daily recording – reasonable record length - > 15% gaps unreliable months
No observed data	D	3 – reasonable	Accuracy reasonable - daily recording – reasonable record length - < 15% gaps unreliable months
		4 – Good	Accuracy good for low flows not for high flows - automatic recording – reasonable record length - < 10% gaps unreliable months
Natural flow data			
Simulated based on good rainfall data and good calibration	A	Also take into account the reliability of the observed flow used for calibration purposes – if it is only reasonable rather give the natural flow a *B* rating.	
Simulated based on good rainfall data and reasonable calibration	B		
Simulated using regional parameters & reasonable rainfall data	C		
Estimations based on assumptions & nearby catchments with more detail data etc.	D		
No natural flow data	E		
Rainfall data (Catchment & point rainfall data)			
Good to excellent	A	Derived from reliable selected rain fall data that were verified and patched. A typical selection process for individual rainfall gauges would include: - A reasonable record length 30 to 40 years or more - Not more than 8% to 10% of the total observed record should consist of unreliable monthly data.	

Data and rating description	Rating	Additional rating description and notes
		- A gauge should lie geographically inside the sub-catchment or nearby in an adjacent catchment - A consistent mass plot which shows a straight line with a constant gradient for the full period of the record
Reasonable	B	Derived from reliable selected rain fall data that were verified and patched but with some shortcomings such as short records, not sufficient number of gauges, etc..
Poor	C	Quality of rainfall data suspicious & lack of data
No data	D	No data
Evaporation data		
Good to excellent	A	Long reliable record with less than approximately 10% unreliable data
Reasonable	B	Record length, and reliability reasonable
Poor	C	Quality of rainfall data suspicious & lack of data
No data	D	No data
Data general		
Good to excellent	A	
Reasonable	B	
Poor	C	
No data	D	

2.3 Description of the database inventory

As indicated in **Section 2.1** the initial database was developed in Excel and will later in the study be incorporated into the Access database which is currently in the process to be developed as part of Task 2 of this study.

For the purpose of this database the study area was divided into different sub-catchments mainly according to those defined in the available study reports. These sub-catchments were sorted first according to the major river catchments the Vaal River and Orange River catchments and then according to the main sub-catchments within each major river catchment. The Vaal River catchment is divided into five main sub-catchments as described in **Table 2-3** and shown in **Figure A-1** of **Appendix A**.

Table 2-3: Main sub-catchments in the Vaal River catchment

Main Sub-catchment		Description
Name	Area (km²)	
Upper Vaal	38 638	Vaal River catchment from Vaal Dam and upstream
Vaal Barrage	8 651	Vaal River catchment between Vaal Dam & Vaal Barrage
Middle Vaal	60 836	Vaal River catchment between Vaal Barrage and Bloemhof Dam
Lower Vaal	53 787	Vaal River catchment downstream of Bloemhof Dam excluding the the Riet and Modder River catchments
Riet/Modder	27 627	The combined Riet and Modder River catchments
Total	189 539	Total Vaal River Catchment

The Orange River catchment (excluding the Vaal River catchment) is divided into seven main sub-catchments which also take into account the country wherein it is located. The Orange River main sub-catchments is described in **Table 2-4** and shown in **Figure A-1** of **Appendix A.**

The sub-catchments as per main sub-catchment are given in **Table 2-5** for both the Vaal and Orange River catchments and are shown in **Figure A-2** of **Appendix A**. As part of the Lesotho Lowlands Study, updated hydrology was prepared for smaller sub-catchments within Lesotho, as indicated in **Table 2-5** and shown in **Figure A-3** of **Appendix A**. Several data elements were covered in the inventory with regards to the following data categories: i.e. catchment area, observed flow, natural flow, catchment rainfall, point rainfall, evaporation, land use and the source of the data. For each of the sub-catchments as defined in **Table 2-5** metadata were provided for all the selected data elements as and when it was available from existing documents. The importance of the data was indicated according to the data importance index as defined in **Table 2-1**.

Table 2-4: Main sub-catchments in the Orange River catchment

Main Sub-catchment		Description
Name	Area (km²)	
Senqu	24 752	Upper reaches and origin of the Orange River in Lesotho
Upper Orange	48 595	Orange River upstream of Vanderkloof Dam and downstream of Welbedacht Dam and the Lesotho Border at Oranjedraai.
Caledon	15 245	Caledon River catchment from Welbedacht Dam and upstream (includes parts of RSA and Lesotho)
Lower Orange RSA	326 173	Orange River catchment downstream of Vanderkloof Dam and the Vaal River confluence excluding the Lower Orange Areas located in Botswana and Namibia
Lower Orange Botswana	71 000	The Orange River catchment located in Botswana
Lower Orange Namibia	164 166	The Orange River catchment located in Namibia excluding the Fish River (Namibia)
Fish River Namibia	95 680	The total Fish River catchment in Namibia
Total	745 611	Total Orange River Catchment excluding Vaal River

The confidence one has in the existing data was included in the inventory for each of the data categories and was based on the data confidence ranking system defined in **Table 2-2**.

Details of the data elements included in the inventory for each of the data categories are given in **Table 2-6.** The gross and net areas are given for sub-catchments. The gross area refers to the total area in km² of the sub-catchment and the net area to the area that contributes to the river runoff. Information with regards to the net area was unfortuanatelly not always available from existing reports. In some areas which are relatively flat, part of the sub-catchment drains to local pans, so that only a portion of the runoff will be reaching the river. Only the area that contributes to runoff draining to the river is regarded as the effective area and is referred to as the net catchment area. There will most probably also be non contributing or endoreic areas in Namibia and Botswana, although no data was available in this regard.

Under the observed flow category, only the observed flows used in the final hydrology calibration process were included and not all the available observed flow in the sub-catchment. In the process of generating hydrology for a study area, the best available flow records are selected for calibration purposes. The selection of these gauges depends on the location of key points in the catchment, the reliability of the flow data, the amount of missing or unreliable monthly flow data and the available record length. It is also important to note that the observed flow represents the total flow from the upstream catchment flowing past the point of observation. The natural flow refers to the incremental flow from the sub-catchment and therefore excludes the flow from the upstream sub-catchments.

Table 2-5: Sub-catchments within each main sub-catchment

Vaal River Basin		Orange River Basin (excluding Vaal)	
Main sub-catchment	Sub-catchment name & reference no.	Main sub-catchment	Sub-catchment name & reference no.
Upper Vaal	R1-Delangesdrift	Senqu	L1-Katse Dam
	R2-Frankfort		L2-Malatsi possible Dam
	R3-Grootdraai Dam		L3-Mashai possible Dam
	R4-Sterkfontein Dam		L4-Matsoku Weir
	R5-Vaal Dam		L5-Mohale Dam
Vaal Barrage	R6-Vaal Barrage		L6-Ntoahe possible dam
	R7-Klip River		L7-Tsoelike possible dam
	R8-Suikerbosrand River		L8-Oranjedraai
Middle Vaal	R9-Allemanskraal Dam		*L9-Makhaleng 1
	R10-Bloemhof Dam		*L10-Makhaleng 2
	R11-Boskop Dam	Upper Orange	R36-Aliwal Noord
	R12-Erfenis Dam		R37-Gariep Dummy Dam
	R13-Klerkskraal Dam		R38-Vanderkloof Dam
	R14-Possible Klipbank Dam		R39-Kraai River
	R15-Klipdrift Dam		R40-Gariep Dam
	R16-Koppies Dam	Caledon	L11-Hlotse possible dam
	R17-Possible Kromdraai Dam		L12-Katjiesberg possible dam
	R18-Johan Neser Dam		R41-Knellpoort Dam
	R19-Possible Rietfontein Dam		R42-Waterpoort possible dam
	R20-Rietspruit Dam		R43-Welbedacht Dam
	R21-Lower Sand/Vet River		+L13-Hlotse possible dam 1
Lower Vaal	R22-Wentzel Dam		+L14-Hlotse possible dam 2
	R23-Baberspan		[$]L15-Ngoajane possible dam 1
	R24-Taung Dam		[$]L16- Ngoajane possible dam 2
			[$]L17- Muela Dam
	R25-Spitskop Dam	Lower Orange RSA	R44-Boegoeberg Weir
	R26-Lower Harts		R45-Vioolsdrift/Mouth
	R27-Vaalharts Weir	Lower Orange Botswana	B1- Nossop & Molopo catchment
	R28-De Hoop Weir		
	R29-Douglas Weir	Lower Orange Namibia	N1-Daan Viljoen Dam
Riet/Modder	Aucampshoop		N2-Otjivero Dam

Vaal River Basin		Orange River Basin (excluding Vaal)	
Main sub-catchment	Sub-catchment name & reference no.	Main sub-catchment	Sub-catchment name & reference no.
	Kalkfontein Dam		N3-Nossop remainder
	Krugersdrift Dam		N4-Nauaspoort Dam
	Rustfontein Dam		N5-Oanob Dam
	Tierpoort Dam		N6-Auob remainder
	Tweerivier		N7-Tsamab Dam
			N8-Dreihoek Dam
			N9-Quaternary 442 & 481 & remainder of 482 & 483
			N10-Quaternary484
			N11-Quaternary485
		Fish River Namibia	N12-Hardap Dam
			N13-Konkiep
			N14-Lower Fish possible dam
			N15-Naute Dam
			N16Seeheim

Notes : * - As part of the Lesotho Lowlands Study the Oranjedraai sub-catchment were sub-divided into these two sub-catchments.

+ - As part of the Lesotho Lowlands Study the Hlotse sub-catchment were sub- divided into these two sub-catchments.

$ - As part of the Lesotho Lowlands Study the Katjiesberg sub-catchment were sub-divided into these three sub-catchments.

The unit runoff refers to the average mm runoff from the catchment and for the observed flows will represent the unit runoff from the total catchment upstream of the gauge. The unit runoff given for the natural flow refers to the incremental flow and therefore represents the unit runoff from the incremental catchment only.

Rainfall data is the primary input data used in rainfall runoff models to simulate natural runoff. It is therefore very important that rainfall records are thoroughly checked, evaluated, verified and patched before it can be used to simulate catchment runoff. Only the final selected rainfall gauges used to create a representative rainfall record for a sub-catchment were included in the inventory. The catchment rainfall record is in most cases a percentage rainfall file which expresses the monthly rainfall as a percentage of the mean annual precipitation of the sub-catchment. The point rainfall file is used in models to determine the water balance of large storage reservoirs and therefore represents the mm rainfall at the point of the dam. The point rainfall file thus contains monthly rainfall data in mm for the total record period.

Table 2-6: Data elements included in the inventory

Data Category	Data elements	
Catchments area *	Gross area in km²	
	Net area in km²	
Observed flow*	Flow gauge name	
	Flow gauge number	
	Record period used	
	Statistics	Average (million m³/a)
		Standard deviation (million m³)
		Coefficient of variance
		Unit runoff (mm)
Natural flow*	File name	
	Record period	
	Statistics	Average (million m³/a)
		Standard deviation (million m³)
		Coefficient of variance
		Unit runoff (mm)
Catchment Rainfall*	Rainfall gauging stations used	
	File name	
	Record period	
	Statistics	Average (mm/a)
		Standard deviation (mm)
		Coefficient of variance
Point Rainfall*	File name	
	Name of dam	
	Record period	
	Statistics	Average (mm)
		Standard deviation (mm)
		Coefficient of variance
Evaporation*	Symonspan evaporation (mm/a)	
	A-pan evaporation (mm/a)	
	Dam evaporation (mm/a)	Name of the dam
Land use*	Small dams	Total storage (million m³)
	Impervious area	Area (km²)
Data source	Study name	

	Report name & number	
Modelling tools	Used for flow data	Name of model
	Used for rainfall data	Name of model

Note:* - Data confidence and data importance ranking were carried out for each of these data categories.

Evaporation data used in the hydrological studies is in most cases only 12 monthly values representing the average gross evaporation for each month. Gross evaporation refers to the evaporation from a pan or dam as if no rainfall occurred during the month. The net evaporation is obtained when the effect of rainfall is added. In the RSA Symons-pan evaporation is generally used in hydrological analysis as well as to obtain lake evaporation. In Namibia and Botswana A-pan evaporation is used in stead.

The land use data category only includes land use data that is not captured under the Task 8 (Water requirements). Land use that is included in the inventory typically is small or farm dams as well as impervious areas within larger urban areas. To provide some indication of the extent of these land use activities, the total combined storage in million m^3 of all the small dams within the sub-catchment and/or the total impervious area (km^2) in the sub-catchment were captured in the inventory.

3 SITUATION ASSESSMENT OF HYDROMETROLOGICAL CONDITIONS IN ORANGE RIVER BASIN

3.1 General

The Orange River rises as two main river systems, the Orange River and its associated tributaries, and the Vaal River and its associated tributaries. The Orange River originates in the Lesotho Highlands at elevations of about 3 300m above sea level. In Lesotho the Orange River is known as the Senqu River and only when it enters the RSA is it referred to as the Orange River. The river flows west for approximately 2 200km to the Atlantic Ocean and for the last 600km forms the border between the RSA and Namibia. The Vaal River catchment varies in elevation from about 3 200m above sea level at the South Eastern boundary in the Drakensberg to approximately 970m above sea level at its confluence with the Orange River close to Douglas. Downstream of Douglas the Orange River is joined by the Ongers/Brak River and the Hartbees River from the south and the Molopo and Fish Rivers from the North. The Molopo and its tributary the Nossob form the boundary between the RSA and Botswana while the Fish River drains a large portion of the Orange River catchment within Namibia.

To be able to properly develop and manage a large water resource such as the Orange River, it is of utmost importance that sufficient and reliable hydrological data are available to be used as the main input to any water resource system analyses. The basic approach followed in hydrological studies to be able to obtain reliable hydrological data sets can be summarised as follows:

- Sub-divide the whole catchment into sufficient smaller sub-catchments, representing key points in the system such as existing and future major dams as well as other sites where reliable observed flow data are available from existing flow gauging stations.
- Collecting and collating of key data which includes:
    - observed rainfall data from gauging stations. These stations must be well distributed throughout each sub-catchment and are selected to be used as the main input to the rainfall runoff simulation models,
    - observed data from stream flow gauges, preferably for each sub-catchment. These stream flow gauges are a combination of purpose built gauging stations and dams,

    - evaporation data for each sub-catchment (Class A-pan and Symonspan),
    - all water use data, which typically include irrigation, urban, industrial, mining, domestic, forestation, transmission losses, environmental requirements, etc.
- Pre-calibration data manipulation:
    - the quality of the data for each rainfall station within or close to the study area is checked by considering the record length, amount of missing and unreliable data and by producing mass plots to check the consistency of the record,
    - infilling and patching of the missing and unreliable data by using acceptable techniques such as multiple linear regression with other stations or models specifically developed for this purpose such as ClassR & PatchR,
    - using finally selected and patched rainfall records for each sub-catchment, a representative catchment rainfall record is created for each sub-catchment that covers the total simulation period selected for the specific study and includes the data from a couple of rainfall gauging stations distributed over the sub-catchment,
    - evaluate the quality of the stream flow data by checking record lengths, reliability of stage/discharge ratings, the amount of missing and unreliable data etc.,
    - examine water use data and taking it back in time. This is important as rainfall runoff modelling is based on the principle of modelling rainfall against "naturalised runoff", which is runoff that is unaffected by human development. This is required as it is assumed that rainfall is not affected by human developments and it will not be possible to model and calibrate the modelled runoff against a non-stationary time series such as observed runoff, which is affected by human developments. To obtain naturalised runoff, the effect of the growing demands is removed from the observed flow record.
- Rainfall runoff Model Calibration:
    - Calibrate the rainfall runoff model on an observed flow sequence to produce a simulated record that provides the best possible fit to the observed flow, while at the same time respecting the physical realities of the sub-catchment.

- This process is carried out for all the sub-catchments, resulting in monthly incremental natural runoff records for each sub-catchment, covering the total simulation period to be used in the study.
- For the purpose of the system analysis, reliable monthly natural flow records of at least 60 to 70 years in length are required for each sub-catchment. In the system analysis the hydrology of all the sub-catchments are included and water demands representative of a selected development level can be imposed on the system, to determine the yield characteristics of the system or sub-systems at the specific development level.

3.2 Rainfall Data

The mean annual precipitation (MAP) in the Orange River Basin vary from as high as 1 200mm in the Lesotho Highlands to less than 50mm in the Richtersveld and parts of Namibia in the Lower Orange where the Orange River forms the border between the RSA and Namibia. (See **Figure A-4** of **Appendix A**)

Rainfall data are possibly the most important data used in a hydrological analysis, as it forms the basis of the runoff generated in each sub-catchment. It is therefore essential that rainfall data are checked and infilled properly before being used in subsequent phases of the hydrological process. The data confidence ranking system was therefore designed to capture the level of detail of the rainfall data checking, verification and patching processes for each of the catchment rainfall records.

Included in the hydrological data base developed for this study are details of the final catchment and point rainfall records that were created in previous studies for the different sub-catchments within the whole Orange River Basin. Although there are many more rainfall gauges within a sub-catchment, only those finally selected and used to create the average sub-catchment rainfall record are listed in the data base. In some areas within the Orange River basin no hydrological studies were previously carried out, and although raw rainfall data do exist for these areas, this data were not captured in the data base as it was not verified and checked for hydrological purposes.

The catchment rainfall files are mostly a percentage rainfall file, expressing the monthly rainfall as a percentage of the Mean Annual Precipitation (MAP) of the specific sub-catchment. The point rainfall files are a monthly rainfall file in mm and represent the point rainfall on a specific dam in a sub-catchment.

Rainfall data were rated for most of the sub-catchments as good to excellent as indicated in **Table 3-1.** Lower ratings were limited mainly to the low rainfall areas in the Lower Orange within the RSA, Namibia and Botswana.

A rainfall isohyetal map was produced for the entire Orange River basin, based on the isohyetal maps received from Namibia, Botswana and the RSA (RSA isohyetal map already included Lesotho) (See **Figure A-4** of **Appendix A)**. The isohyets from the Namibia and the RSA compared very well along the borders between the two countries. The isohyets received from Botswana and those from the RSA showed some discrepancies along the RSA/Botswana in particular at the lower rainfall areas. The Botswana and RSA isohyets were therefore slightly adjusted to obtain a smooth transition from the one country to the other. The discrepancies between the isohyets before adjustment are also shown on the map. The isohyets received from Botswana did not show the 200mm isohyet at the most southern point of Botwana and it was based on an extension of the RSA isohyet. The combined isohyetal map as given in **Appendix A, Figure A-4**, should in general still provide a good indication of the variance in rainfall over the entire Orange River Basin.

Table 3-1 : Rating of rainfall data

Main Sub-catchment	Rating
Upper Vaal	Good to excellent
Vaal Barrage	Good to excellent
Middle Vaal	Good to excellent
Lower Vaal	Good to excellent
Riet/Modder	Good to excellent
Senqu	Generally good to excellent, except for the rainfall records used for the Makhaleng Dam catchments used in the Lesotho Lowlands Study which were rated as reasonable.
Upper Orange	Good to excellent
Caledon	Generally good to excellent, except for the rainfall records used for the Hlotse and Hololo Dam catchments used in the Lesotho Lowlands Study which were rated as reasonable..
Lower Orange RSA	Rated as reasonable as rainfall data were obtained from the WR90 publications and is not the product of a detailed hydrological study.
Lower Orange Botswana	No data available
Lower Orange Namibia	No data available
Fish River Namibia	Rated as reasonable for some gauging stations that were used in previous studies but no catchment rainfall files were available for any of the sub-catchments.

3.3 Evaporation

S-pan evaporation varies in the Orange River basin from in excess of 2 600mm/a in the central parts of the Lower Orange, most of Namibia and western part of Botswana to approximately 1 200mm/a in the Lesotho Highlands (See **Figure A-5** in **Appendix A**).

Evaporation is one of the primary inputs to catchment rainfall runoff models and is also used to determine water losses from wetlands, reservoirs and aquifers as well as for determining water requirements of crops under irrigation. Two types of evaporation pans are commonly used to measure evaporation namely the Symons pan and the American Class A-pan. The A-pan is a round pan which is installed on a support above the ground and is mainly used for agricultural purposes to determine irrigation demands of different crops. The Symons pan (S-Pan) is a square pan and is buried in the ground. In the RSA the S-pan are widely used to determine the free surface lake evaporation at dam sites. Evaporation from the S- and A-pans differs significantly and the A-pan evaporation is on average 1.1 to 1.3 times higher than the S-pan values.

Data captured in the data base for this study refers mainly to S-pan evaporation, as S-pan evaporation is used as basis in the rainfall runoff models as well as to determine lake evaporation. Due to the lower variation in the annual evaporation at a site, only 12 monthly evaporation values are generally required in hydrological analysis which represents the average monthly evaporation for each of the months in a year. The point evaporation as used for the major dams in the basin is also captured in the data base and is referred to as lake evaporation.

Most of the evaporation data as used in the previous studies for the various sub-catchments were rated as reasonable as evaporation data in general did not go through a thorough checking, verification and patching process as in the case of the rainfall data. Evaporation data were in general obtained from the "Surface Water Resources of South Africa 1990" publication.

Table 3-2: Rating of evaporation data

Main Sub-catchment	Rating
Upper Vaal	Reasonable
Vaal Barrage	Reasonable
Middle Vaal	Reasonable
Lower Vaal	Reasonable
Riet/Modder	Reasonable
Senqu	Although data was used in the previous studies, only lake evaporation were

Main Sub-catchment	Rating
	given in the reports and no reference were made to catchment evaporation except for the areas covered by the recent Lesotho Lowlands Study (Makhaleng Dam catchments) Given data were however rated as Reasonable.
Upper Orange	Reasonable
Caledon	Reasonable
Lower Orange RSA	Reasonable
Lower Orange Botswana	No data available
Lower Orange Namibia	No data available
Fish River Namibia	Rated as reasonable for Hardap and Naute Dam and poor for possible Lower Fish Dam but no catchment evaporation data were available

The mean annual evaporation (MAE) isoline coverage as given in **Figure A-5** of **Appendix A,** were prepared from MAE isoline coverages received from RSA and Namibia. Lesotho was fully covered by the RSA isoline map and detail was therefore not required from Lesotho. No evaporation isolines were available from Botswana and only A-pan evaporation for a few stations were available as indicated on **Figure A-5** of **Appendix A.** These individual values however seem to tie in with the RSA and Namibia isolines. MAE isolines received from Namibia referred to A-pan evaporation. A-pan evaporation is on average 1.1 to 1.3 times higher than S-pan values. The following equation to convert S-pan to A-pan evaporation was obtained from the "Surface Water Resources of South Africa 1990":

MAE (S-pan) = 130 + 0.726 MAE (A-pan)

When this equation was used to convert the A-pan MAE isolines received from Namibia to equivalent S-pan isolines, the converted S-pan isolines did not match well with the S-pan isolines used in the RSA. To be able to obtain a reasonable match between the two sets of MAE isolines a factor of between 0.85 and 0.91 was required to convert Namibian A-pan to equivalent RSA S-pan values. This means that the Namibia A-pan values are on average 1.1 to 1.18 times higher than the RSA S-pan values. The MAE isolines for Namibia as shown on **Figure A-5** of **Appendix A** were derived from the Namibian A-pan isolines using conversion factors of between 0.85 to 0.91.

3.4 Land use impacting on runoff

Although there are a large variety of land use data that will impact on the available runoff, most of these developments will be addressed in Tasks 3 and 8, review of existing infrastructure and summary of water requirements respectively. As part of task 4 (Review of existing Hydrology) the focus will only be on small dams and urbanised areas which are not covered in tasks 3 and 8.

The confidence in the available data was regarded as reasonable in all the sub-catchments where such data were captured in the previous study reports. No data were available for the entire Lower Orange as well as for the Senqu catchment.

The extent of these developments in each of the main sub-catchments is shown in **Figure A-6** of **Appendix A.** The storage in small dams accumulates to a total of 811 million m^3, which is equivalent to that of a very large storage dam. The only impervious area that was significant enough to be taken into account in the hydrological studies was that of Johannesburg and surrounding areas within the Vaal River catchment which accumulated to 1.3 km^2. The effect on the reduction or increase in runoff for any of these developments, were unfortunately not given in the existing hydrology reports.

3.5 Flow data

Reliable observed flow records of sufficient length provides extremely valuable data to be used in any hydrological analysis as it captures the characteristics of the actual flow generated in the catchment over time. The observed records are however seldom used as is in system analyses, due to the fact that it also captures the effects of human related development over time, in the catchment. One therefore needs to remove the effects of human development from the flow record, to first obtain a naturalised flow record which can be used in the system analysis. This process is briefly described in **Section 3.1**. There are still some areas, located mainly in the drier arid catchments, where human development had little or no effect on the runoff from the sub-catchment. In such cases the observed records can be used to represent the flow under natural conditions.

Observed flow data that were selected in previous studies as the best and most suitable records to be used for calibration purposes or as a natural flow record where no or little human development occurred in the catchment, were included in the data base and rated according to the confidence ranking system. Results of the rating are summarised in **Table 3-3.** Although there are lots of other gauging stations with flow records available in the study area, they were not included as they did not contribute to the final natural flow sequences generated for the Orange River Basin.

Table 3-3: Rating of observed flow data

Main Sub-catchment	Rating	Description
Upper Vaal	A4 to A5	Data was checked & verified & patched and accuracy regarded as good to excellent
Vaal Barrage	A4 to A5	Data was checked & verified & patched and accuracy regarded as good to excellent
Middle Vaal	A1 to A5	Data was checked & verified & patched and accuracy regarded as poor to excellent, although most were given a 3 or 4 accuracy rating which is reasonable to good.
Lower Vaal	A3 to A4	Data was checked & verified & patched and accuracy regarded as reasonable to good.
Riet/Modder	A2 to A4	Data was checked & verified & patched and accuracy regarded as use with caution to good, but most were regarded as reasonable.
Senqu	A2 to A4	Data was checked & verified & patched and accuracy regarded as use with caution to good.
Upper Orange	A3 to A4	Data was checked & verified & patched and accuracy regarded as reasonable to good.
Caledon	A3	Data was checked & verified & patched and accuracy regarded as reasonable.
Lower Orange RSA	No data	No detail hydrology study was carried out for this area.
Lower Orange Botswana	No data	No detail hydrology study was carried out for this area.
Lower Orange Namibia	C1 to B4	Limited data was available and cover only a small portion of the total sub-catchment area. Most of the data was rated as B4 which means data was checked & verified and accuracy is good.
Fish River Namibia	C2 to B4	Most of the data rated B3 to B4. This means that data was checked & verified and accuracy is regarded as reasonable to good.

From **Table 3-3** it is evident that the observed flow data in the upstream catchments is generally rated as very good and the rating decreases as one progress downstream into the more arid areas.

As natural flows is most widely used in hydrological and system analyses, the remainder of this section focuses on the natural flows or flows under virgin conditions as it is also referred to. The total natural flow generated in the Orange River Basin in excess of 11 500 million m³/a. The natural runoff generated in large parts of Namibia and Botswana is not available from existing reports and is not included in the total of 11 500 million m³/a given in **Table 3-1**. Most of the current unknown flow volumes from these areas in Namibia and Bostwana are, however, not expected to reach the Orange River and is of local importance only.

As result of non-contributing or endoreic areas (localised areas where runoff flows into pans and evaporate and is therefore not contributing to the river flow) al the runoff generated in a sub-catchment will not contribute to river flow. Transmission losses in the Fish River (Namibia) are very high and result in a significant reduction in the runoff volume that will eventually reach the Orange River. To provide an indication of the runoff volume that is expected to eventually reach the Orange River the "MAR adjusted" column was added to **Table 3-4**. From this data it is evident that approximately 11 400 million m³ is expected to reach the Orange River. Due to the extremely dry conditions in the Lower Orange River with very little incremental flow reaching the Orange River in this area, large volumes of the flow in the Lower Orange River is utilised to satisfy river requirements such as evaporation, evapo-transpiration and seepage. This will result in a further reduction of approximately 615 million m³ in the flow, so that under natural conditions it is expected that only approximately 10 800 million m³ will reach the Orange River mouth.

Table 3-4: Summary of natural flow data

Name	MAR (million m³/a)	MAR adjusted	Percentage of total runoff	Unit runoff (mm/a)
Vaal River Catchment				
Upper Vaal	1 977	1 977	17.3	51.2
Vaal Barrage	257	257	2.2	29.7
Middle Vaal	1 076	1 076	9.4	17.8
Lower Vaal	191	191	1.7	3.6
Riet/Modder	406	406	3.5	14.7
Sub-total	3 907	3 907	34.1	20.6
Orange River Catchment				
Senqu	4 038	4 038	35.3	163.2
Upper Orange	1 450	1 450	12.7	29.8
Caledon	1 217	1 217	10.6	79.8
Lower Orange RSA	b) 420	b) 330	2.9	1.0
Lower Orange Botswana	No data available			
Lower Orange Namibia	c) 29	c) 7	0.1	1.5
Fish River Namibia	d) 706	d) 494	4.3	5.2
Sub-total	7 860	7 536	65.9	10.1
Total	a) 11 767	a) 11 443	Total Orange & Vaal	

Notes: a) Due to river evaporation, evapo-transpiration and seepage losses along the Lower Orange River the total volume of 11 443 million m³/a will not be able to reach the Orange River mouth. These river requirements are dependant on the flow in the river and can vary between 575 to 989 million m³/a for average flow rates of between 50 m³/s to 400 m³/s respectively. Under the current operating conditions with an average flow of approximately 70 m³/s the river requirements is estimated to be in the order of 615 million m³/a.

b) The hydrology for the Lower Orange RSA was produced at a lower level of detail due to the fact that area, although large in size, contributes to less than 3% of the total flow in the Orange. In the current yield models a total flow of 218 million m³/a is used, which is not the natural flow in the true sense of the meaning, but rather represents the inflow to the Orange River from this area, under current conditions. The natural flow generated in this area is 420 million m³/a, but a large amount of this is not reaching the Orange River, due to non contributing areas as well as large pans in the Sak and Brak rivers, from where extensive evaporation losses occur. Flow from the Molopo is not reaching the Orange River as sand dunes near Noenieput have blocked its course for at least the last 1000 years. The natural flow still reaching the Orange River has not been determined in detail, but is expected to be in the order of 330 million m³/a.

c) The only flow data available for this area is for Oanob Dam in upper reaches of the Auob, Otjivero and Daan Viljoen dams in the upper reaches of the Nossob as well as Dreihuk and Tsamab dams in the Hom and Ham rivers respectively, which is located relatively close to the main Orange River. These areas represent a very small portion of the total Lower Orange Namibia sub-catchment and will therefore not reflect the total volume of runoff generated in this area. The Auob and Nossob rivers are both tributaries of the Molopo River, and flow from these rivers will not reach the main Orange River. Under natural conditions it will only be the flow from the Dreihuk and Tsamab dam catchments that can reach the main stem of the Orange River. The 7 million m³/a from those areas, however, do not represent all the natural runoff that will enter the main Orange River from the Lower Orange Namibia sub-catchment, as all the small tributaries close to the main Orange River will to a certain extent contribute to the runoff in the Orange River, although small.

d) The total volume of runoff generated in the Fish River catchment (706 million m³/a) is quite substantial. Due to the erratic nature of the run-off, the low rain fall and high evaporation in this catchment, large volumes of transmission losses occur along the river reaches, and it is estimated that only 494 million m³/a will on average reach the Orange River under natural conditions.

It is interesting to note that although the Lower Orange (Fish River Excluded) sub-catchment area represents approximately 35% of the total Orange River catchment area, only 3% of the runoff reaching the Orange River is generated in this sub-catchment, while 35% of the runoff is generated in the Senqu Catchment, which in turn represents as little as 2.6% of the total Orange River catchment area. The runoff contributions from different main sub-catchments in the Orange River Basin are given in **Table 3-4** and shown on **Figure A-7** of **Appendix A.**

Statistics of the natural flows are summarised in **Table 3.5,** and it is evident that in sub-catchments with a high unit runoff such as Senqu (163 mm/a) the coefficient of variance (CV) is typically low (0.35). In arid areas where CV's as high as 3 to 5 are common, the unit runoff is as low as 1mm/a. The change in the CV over the entire basin is clearly evident from **Figure A-8** of **Appendix A** where it slowly changes from relatively low values in the higher rainfall areas to high values it the arid areas. Some lower CV values are found in the Boskop and Klerkskraal sub-catchments which seem like outliers. These values are however strongly affected by base flows from dolomitic springs in these sub-catchments and are therefore not reflecting the characteristics of rainfall runoff on it's own.

Table 3-5: Natural flow statistics

Name	MAR (million m³/a)	STD. DEV *(million m³/a)	CV *	Unit runoff (mm/a)
Vaal River Catchment				
Upper Vaal	1 977	1 570	0.79 (0.73 – 0.84)	51.2
Vaal Barrage	257	209	0.81 (0.74 – 0.92)	29.7
Middle Vaal	1 076	967	0.90 (0.47 - 0.93)	17.8
Lower Vaal	191	400	2.10 (1.51 – 3.46)	3.6
Riet/Modder	406	617	1.52 (1.17 – 3.04)	14.7
Orange River Catchment				
Senqu	4 038	2 015	0.50 (0.35 – 0.58)	163.2
Upper Orange	1 450	1 507	1.04 (0.86 – 1.71)	29.8
Caledon	1 217	885	0.73 (0.37 – 1.58)	79.8
Lower Orange RSA	330	637	1.93 (1.43 – 5.32)	1.0
Lower Orange Botswana	No data available			
Lower Orange Namibia	1) 7	16	2.24 (2.01 – 3.67)	1.5
Fish River Namibia	494	835	1.69 (1.25 – 1.78)	5.2

Note: * - The values in brackets give the range of the CV for the sub-catchments within the main sub-catchment. The single value outside the brackets is the weighted average CV for the main sub-catchment. The standard deviation given for each main sub-catchment was calculated backwards from the CV and therefore also represents a weighted average value. Standard deviation and CV values were only available from the reports for the sub-catchments and not for the main sub-catchments. Details of the standard deviation and CV values for the sub-catchments are given in the data base.

The confidence one has in the natural flow sequences generated from the different studies and which were finally included in the system analysis of the total Orange River System, is of great importance, as it will directly dictate the confidence one has in results from the system analyses. The ratings based on the confidence ranking system as given to the natural flow sequences, are summarised in **Table 3-6** and shown in more detail in **Figure A-9** of **Appendix A**. Ratings given for sub-catchments in the Vaal River, Upper Orange, Caledon and Senqu are in general very good with some exceptions such as for the Sterkfontein Dam sub-catchment in the Upper Vaal and the Aliwal Noord sub-catchment in the Upper Orange.

The large transfer volumes into the Sterkfontein Dam from the Tugela made it almost impossible to obtain an accurate naturalised flow and calibration for this sub-catchment and the generated natural flow was therefore based on regional parameters. The runoff from this sub-catchment is relative small (18 million m³/a) and it represents less than 1 percent of the total flow generated in the Upper Vaal. The lower rating for the Sterkfontein Dam sub-catchment has therefore almost no effect on the larger system.

As result of the high flows in the Orange River relative to the incremental flow from the Aliwal Noord sub-catchment, it was not possible to obtain an accurate indication from the observed flow for the incremental catchment only. The flows for the Aliwal Noord sub-catchment was therefore simulated using the calibrated parameters of the neighbouring Kraai River catchment. Although the total flow from this incremental catchment is not that small (229 million m³/a) it still represents only 3.4 percent of the total natural inflow to Gariep Dam. Inaccuracies in the simulated flow for the Aliwal Noord sub-catchment will thus have a small impact on the larger system.

Ratings for natural flows from the Lower Orange are in general not very good. No natural flow data is available for Botswana and large parts of Namibia. Very little of the runoff generated in these areas is, however, expected to reach the main Orange River. It was therefore decided to include an additional column in **Table 3-6** to indicate the importance of the runoff from a sub-catchment to flow in the Orange River and therefore also to water supply schemes depended on water from the main Orange River.

Table 3-6: Rating of available natural flow data

Main Sub-catchment	Data importance to flow in Orange River	Rating	Description
Upper Vaal	5	1)A to C	Most of sub-catchments received an A to B rating which means good rainfall data and good to reasonable calibrations
Vaal Barrage	5	A to B	Good rainfall data and good to reasonable calibrations
Middle Vaal	5	A to B	Good rainfall data and good to reasonable calibrations
Lower Vaal	4	A to B	Good rainfall data and good to reasonable calibrations
Riet/Modder	5	A to B	Good rainfall data and good to reasonable calibrations
Senqu	5	2)A to B	Most of sub-catchments received an A rating indicating good rainfall data and good

Main Sub-catchment	Data importance to flow in Orange River	Rating	Description
			calibration.
Upper Orange	5	3)B to C	Most of sub-catchments received a B rating which means good rainfall data and reasonable calibrations
Caledon	5	B	Good rainfall data and reasonable calibration
Lower Orange RSA	3	C	Based on flows generated using regional parameters and reasonable rainfall data.
Lower Orange Botswana	2	E	No data is available
Lower Orange Namibia	2	4)E to F	The largest portion of this area received an E rating which means there is no data available
Fish River Namibia	4	B to D	Hardap and Naute dam catchments received a B rating with a C for Seeheim and D for Lower Fish.

Notes: 1) – It is only the Sterkfontein Dam sub-catchment flow which received a C rating. This sub-catchment is very small relative to the remainder of the Upper Vaal catchment.

2) – It is only the smaller sub-catchments from the Lesotho Lowlands Study that was rated as B's

3) – It is only the Aliwal Noord sub-catchment that was rated as C, the rest of the sub-catchments was all rated as B's.

4) – Data were only available for the small sub-catchments just upstream of exiting storage dams in Namibia. These sub-catchments represent less than 9% of the Lower Orange Namibia sub-catchment. The natural flows available for these catchments are simply the observed flows as the effect of development in the catchment on the observed flows is regarded as negligible. The rating given for these sub-catchments were therefore a F, which means that reasonable observed data were used as natural flow due to the low level of development.

The importance of the runoff from the Lower Orange Botswana and Namibia areas are shown as a 2, which means that it will be nice to have this type of information, but will add very little value to the overall hydrology. The natural runoff from these areas will however be of more value for the local area, specifically in some areas of Namibia where existing dams are already utilizing runoff from the sub-catchment.

The flow from the Lower Orange RSA was given a slightly higher importance value of 3 as it contributes in the order of 218 million m³/a to the main Orange River. This will have an effect on the flows in the Orange, and will in particular be valuable in cases where a dam such as the proposed Vioolsdrift Dam is considered in the Lower Orange River.

The flow from the Fish River (Namibia) is regarded as important to the main Orange River, as the total volume reaching the Orange River is quite substantial, approximately 494 million m³/a under natural conditions. Although the existing users from the Orange River downstream of it's confluence with the Fish River is limited, the flow still provide a valuable contribution to the environmental requirements in the river and at the river mouth. Locally within Namibia the Fish River is of high importance and two of Namibia's largest storage dams are located in this catchment, namely Hardap and Naute dams. The natural flows with the highest ratings (B) in the Fish River catchment are those for the Hardap and Naute Dam sub-catchments, which are for local purposes the most important flow data. Although a B rating was given for these two sub-catchments the natural flow for these two sub-catchments should rather be regarded as a low B as it is not at the same level as the other B's. The flows from these two sub-catchments already represent approximately 34% of the total runoff generated in the Fish River catchment. The Seeheim sub-catchment has a C rating which should also be regarded as a low C and represents approximately 47% of the runoff generated in the Fish River catchment. The remaining 19% of the flow data has a low rating (D) and includes the Konkiep and Lower Fish sub-catchments.

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

For system analysis purposes one would in general require natural flow sequences with a relative high confidence rating of an A or at least and B. Confidence ratings of C and lower should preferably not be used. The natural flow data for the total Vaal River catchment as well as the Orange River catchment from Vanderkloof Dam and upstream falls in the A and B confidence rating with the exception of two small areas which will have a negligible affect on results. In the remainder of the Orange River catchment only two sub-catchments (Hardap and Naute) within the Fish River sub-catchment has a B rating which is also regarded as a low B rating. All the rest of the sub-catchment has ratings of a C and less.

This means that on a catchment area basis approximately 32 percent of the area has natural flow records with a confidence rating that is high enough to be used in system analysis. From this 32 percent of the catchment area, approximately 94 percent of the natural flow reaching the Orange River, is however generated. This brings along a total different perspective, showing that on a volume basis only 6% of the natural flow records for the Orange River are not at an acceptable confidence level. This 6% represents the runoff volume that is expected to reach the Orange River main stream and expressed as a volume it would be in the order of 680 million m³/a. This volume was not neglected in previous analyses, but is just not at the desired confidence level. This means that the margin of error is most probably higher than the 10% to 15% generally accepted for hydrology and might be in the range of 25% to 30% (170 to 200 million m³/a error) for 68% of the catchment. Improving these flow records will contribute to an overall improvement in accuracy of approximately 1% which is not much. Considering only the Lower Orange and Fish River inflows the improvement might be in the order of 12%, which need to be taken into account when the focus is on developments in the Lower Orange and Fish River sub-catchment.

Areas where no natural flow records are currently available amount to a total of 220 500 km². Although this area is significant in size, it includes mainly arid and semi arid areas. If the unit runoff for this area is between half to equal that of the Lower Orange RSA, which is also a arid to semi arid area, it means that the runoff generated from the 220 500 km² can be in the order of 110 to 220 million m³/a, of which only approximately 16% (17 to 35 million m³/a) is expected to reach the Orange River. The remainder will only be useful for local use close to the area where it was generated.

Most of this runoff currently evaporates and/or is contributing to the recharging of groundwater resources.

No data was available on small dams in the Senqu and Lower Orange Sub-catchments. It is however expected that small dams in the Senqu sub-catchment will be negligible. In the Lower Orange River catchments the effect of the smaller dams will quite possibly be significant and should be taken into account.

4.2 Recommendations

From the findings and conclusions given in this report the following recommendations are made.

- Upgrade the hydrology for the areas contributing to flow in the main Orange River to at least a B rating. Effect of small dams need to be included.
- Develop and upgrade hydrology for the areas (Lower Orange Namibia and Botswana) that is not contributing to flow in the Orange River main stem, to a confidence level representing at least a C rating. Effect of small dams and endoreic areas need to be included.
- Discrepancies in the rainfall isoline between the different counties need to be resolved (mainly RSA & Botswana).
- Discrepancies in evaporation isoline between the different counties need to be resolved and which evaporation data should be used A-pan or S-pan or both.
- Agreement on the Orange River Basin boundary specifically between Namibia and Botswana need to be reached.
- Standardise the approach that need to be followed to develop hydrology of an acceptable confidence level between the four countries.

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Appendix A

Figures

Figure no

Appendix B

Data Base Inventory